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ABSTRACT

Presented is one of a series of National Aeronautics and Space Administration (NASA) facts about the exploration of Mars. Photographs, showing Mars as seen from Earth through a telescope, show dark markings and polar caps present. Photographs from Mariner 7, Mariner 4, and Mariner 9 are included. Presented is a composite of several Mariner 9 photographs that reveal the summit craters and the cliffs at the base of a high pile of lava, with an altitude trace scheme drawn across a mountain diagram. An explanation of the changes occurring on Mars on the basis of close-up observations by NASA's Mariner 9 is presented. Both the geology and atmosphere of Mars are described. A contour map showing the highest contours in kilometers above and below the level on Mars at which water can exist as a liquid is included. Student involvement is facilitated by the inclusion of three suggested activities and suggested readings. (EB)

NASA Facts
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NF-60/8-75

MARS AS A PLANET

One of a series of NASA Facts about the exploration of Mars.

Surface Features of Mars

The first great change in human attitude toward the planets came in the seventeenth century. With the invention of the telescope the planets were seen to have size, they were no longer points of light like the stars, but worlds that might be similar to the Earth. The second great change came with the space age when close inspection of the planets by spacecraft changed them from remote and distant worlds to places that could be explored.

The first record of anyone seeing features on the surface of Mars is that of Christian Huygens, a Dutch physicist and astronomer. In 1659 he made a rough sketch of a prominent Martian feature now known as the Syrtis Major ("Great Quicksands").

The features on Mars are difficult to observe with small telescopes because although Mars approaches close to Earth compared with most other planets of the Solar System, its physical size is small: a little more than half the diameter of Earth. Classical markings on Mars (Figure 1) appear dark grey or bluish green upon a reddish-ocher background with white polar caps that vary in size with the Martian seasons.

The first major map of Mars was published by Wilhelm Beer and J. H. von Maedler in 1840. But this map bears little resemblance to the Martian features now mapped in great detail by NASA's Mars-orbiting spacecraft, Mariner 9.

Before this spacecraft produced detailed pictures of Mars, controversy raged for many years on the nature of the illusive Martian markings; especially since their intensities and shapes appeared to vary with seasons on Mars. And another great controversy raged on the nature of the seasonal polar caps as to whether they were of ice and snow like Earth's caps, or of frozen carbon dioxide.

Some astronomers claimed that they could see linear markings criss-crossing the planet in intricate geometrical patterns, markings which were popularly called canals, from the Italian "canali" or "channels." A few, such as Percival Lowell in the last century, believed that these linear markings were evidence of intelligent beings on Mars conserving water supplies on a dying planet. This viewpoint was not, however, accepted by the majority of astronomers.

Mars, too, was known to possess an atmosphere. Photographs taken in ultraviolet light, which does not penetrate an atmosphere well, showed a larger disc to Mars than photographs taken in infrared light which penetrates to the actual surface. Moreover, astronomers often observed light markings and hazes which they interpreted as clouds and dust in the atmosphere of Mars.

The first spacecraft to reach Mars, NASA's Mariner 4 (1965), provided only a limited number of telescopic close-ups across the Red Planet. None of the familiar markings that astronomers see from Earth could be identified. But many of the pictures showed craters similar to those on the Moon. Many scientists erroneously concluded that Mars was a moon-like body, its surface shattered and splattered by the impact of large bodies falling from space; some the size of small mountains. A few pointed out, however that there was evidence of linear features on Mars (Figure 2) that could be faults such as those that border rift valleys on Earth, and that these might be evidence of vulcanism on Mars.

Subsequent NASA spacecraft, Mariners 6 and 7 (1969), again revealed heavily cratered terrain, but with some unusual features that were difficult to explain if the Martian surface had been formed solely by the impact of large meteorites. In places, Mars seemed to have collapsed inwards to produce complex patterns of fractures and slumped terrain. Additionally, these pictures revealed that

Figure 1. Mars as seen from Earth through a telescope shows dark markings and polar caps. These vary with the seasons on Mars. This series of Mariner 7 pictures shows rotation of Mars at about the same resolution.

the polar caps probably consisted of thin carbon-dioxide snow which disappears quickly, but with a permanent ice cap over a much smaller area of each polar region. Peculiar ridges near the poles suggested that the ice caps may be layered with dust.

In 1971 Mariner 9 went into orbit around Mars and began a detailed photographic survey of the Martian surface. The first pictures were disappointing. Mars showed a uniform image resembling an old tennis ball with no visible details except for a faint polar cap. The spacecraft had arrived when Mars was engulfed in a monstrous wind storm which shrouded the whole of the planet with clouds of sand and dust (Figure 3).

The storm had started in regions called Hellespontus and Noachis in the southern hemisphere, and then spread rapidly to engulf all the planet. As seen from Earth, detailed markings on Mars faded. As seen from Mariner 9, the yellowish cloud

Figure 2. The first spacecraft (Mariner 4) to arrive at Mars, showed large craters but also hinted at volcanic activity by the presence of a lineament cutting diagonally across the bottom right-hand corner of the picture.

obscured everything, except for the south polar cap and four dark spots.

Intense dust storms had also been observed on Mars in 1892, 1924, 1941, and 1956, and later in 1973. Each engulfed the planet when Mars was at its closest to the Sun (perihelion). It seems that major storms may occur each year on Mars, but are not so easily observed from Earth when Mars is not at the close (perihelic) oppositions.

Gradually the 1971 storm cleared and a group of huge volcanoes was seen, their cratered peaks projecting miles above the settling dust. In sub-

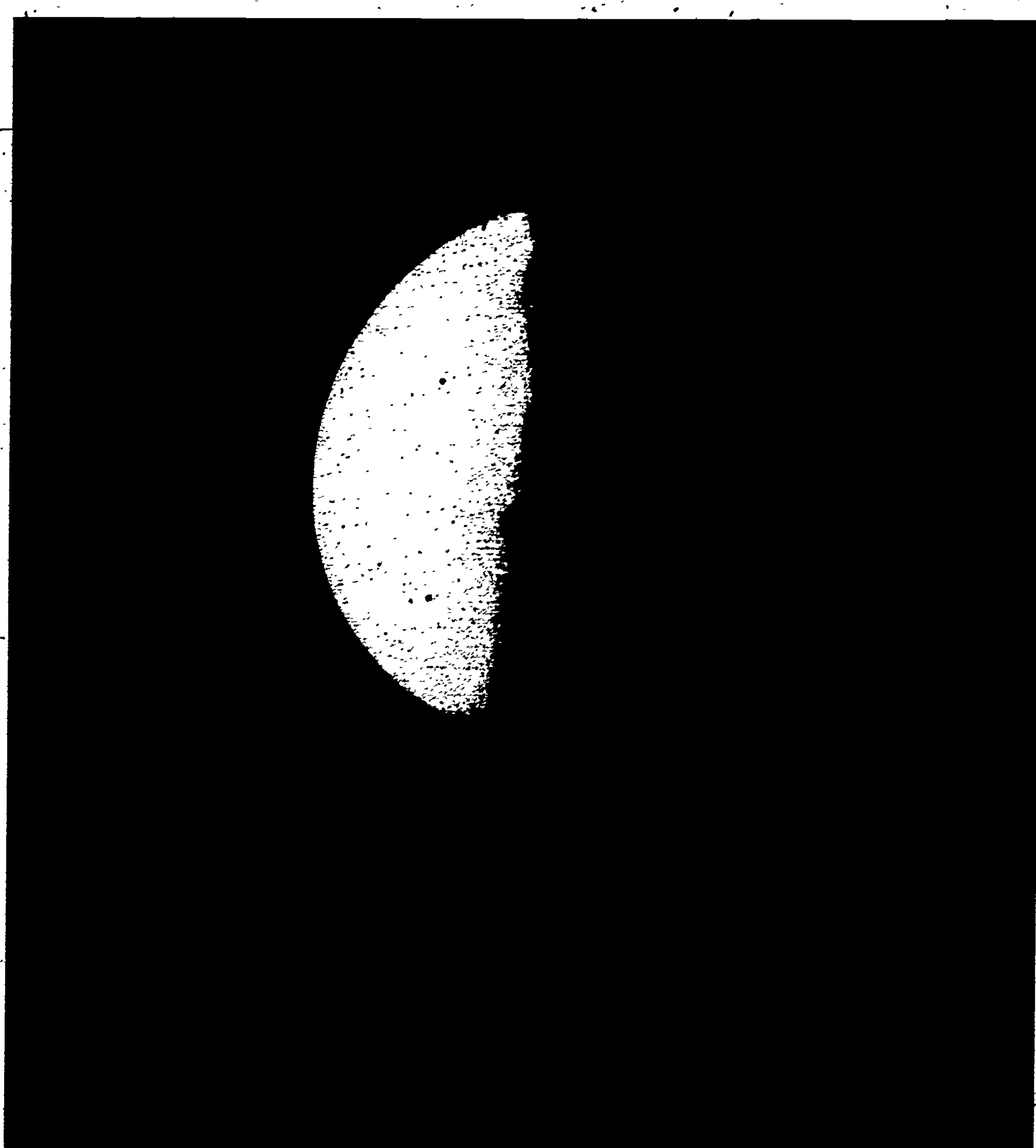

Figure 3. When Mariner 9 arrived at Mars in 1971 the planet was shrouded in dust and only the south polar cap and four dark spots were visible.

Figure 4. A great volcano on Mars, Olympus Mons, is many times larger than Hawaii. This shows a composite of several Mariner 9 photographs that reveal the summit craters and the cliffs at the base of the huge pile of lava. Below the photograph is an altitude trace across this tremendous mountain.

sequent months a completely new interpretation of the Martian features had to be accepted. Mars could not be considered a dead world. About half of the planet's surface is very old and heavily cratered, much like the highlands or the backside of the Moon. The other half is younger terrain containing the biggest volcano known and the equivalent of ocean basins, fractured and overlain with sedimentary and wind-borne deposits.

The big volcano (Figure 4) is seen from Earth as a light spot on Mars. It was called Nix Olympica (Snows of Olympus) but has been renamed Olympus Mons (Mount Olympus) since it is now known to be a mountain, the highest feature on Mars. Olympus Mons peaks at 25 kilometers (15 miles) above the surrounding plains.

About a score of large volcanoes have now been identified on Mars. It is speculated that not very long ago the fiery glow of lava may have filled many of the caldera craters in the throats of these huge volcanic piles. And there is nothing to disprove that these volcanic fires might still be burning, with eruptions taking place again in years to come. Even on Earth, volcanoes often remain dormant for centuries between eruptions.

Another newly-discovered feature on Mars is a unique super Grand Canyon that stretches across the planet a distance equal to the width of the United States. The canyon (Figure 5) is 120 kilometers (75 miles) wide and 6 kilometers (4 miles) deep. Its walls show evidence of erosion as though streams of water have flowed into it from the surface and from underground sources. Also at its eastern end the material that was washed from it appears to be deposited in great plains extending northward toward the pole.

Violent winds may cut through the canyon and its many tributaries as the result of temperature differences along them as they straddle the day-night boundary called the terminator. Winds in the thin atmosphere of Mars must reach as high as 320 kilometers per hour (200 m.p.h.) to raise the planetwide dust storms.

Mars also has giant dust bowls, old impact basins, gouged out by mountain-sized objects

Figure 5. The volcanic area of Mars in Tharsis split the planet's surface in all directions. Along one of the radial faults mighty chasms developed, as shown in this Mariner 9 picture. This Grand Canyon of Mars, known as Tithonius Chasma, is part of a system of canyons called Valles Marineris (after the NASA Mariner spacecraft that first discovered them) that have a length sufficient to reach completely across the United States from the West Coast to the East Coast.

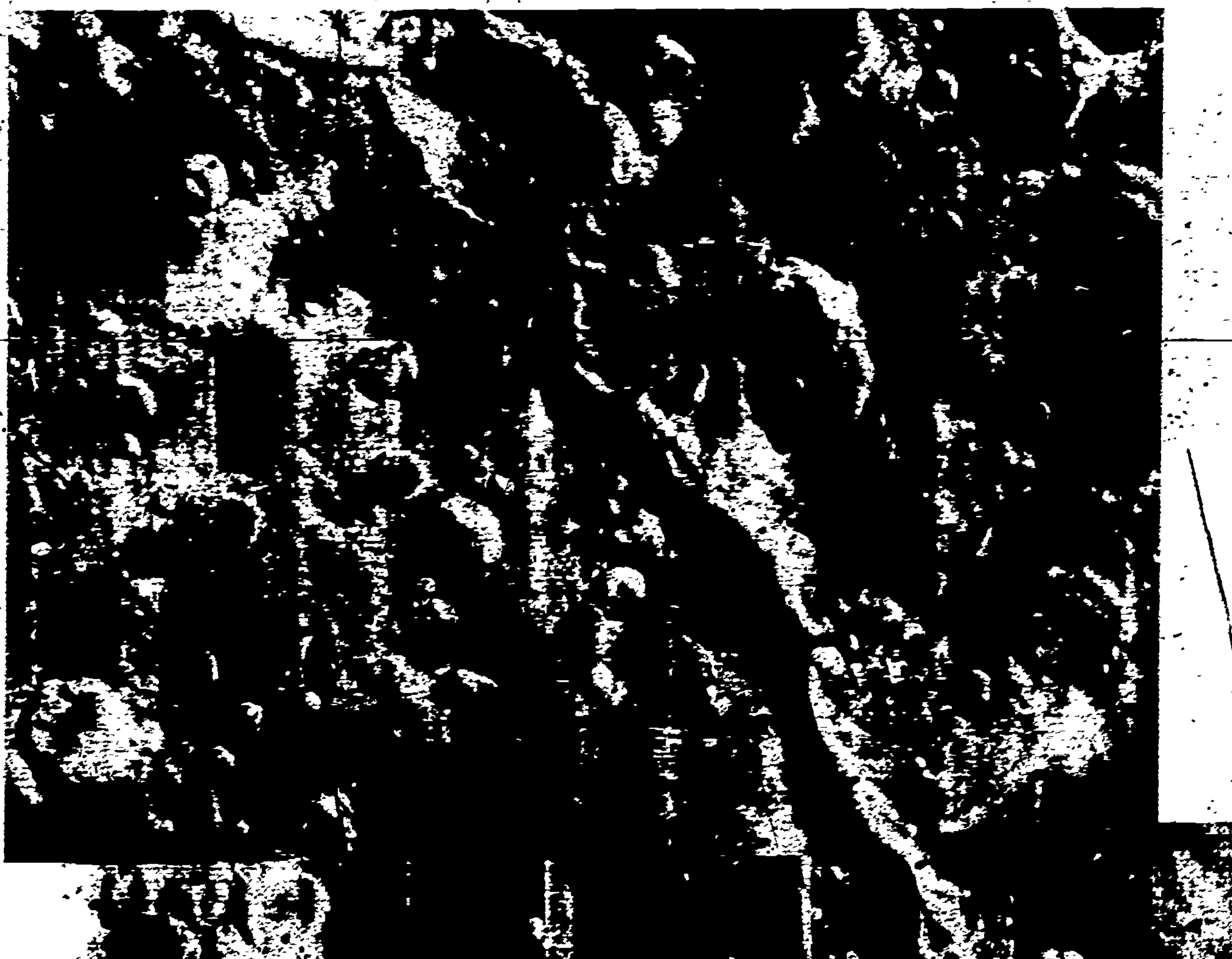

Figure 6. From the highland areas of Mars to the lowlands there are many channels that have the appearance of being dried-up channels, the beds of once mighty rivers rivalling the rivers of Earth. Much material appears to have been carried down these channels and deposited in the Martian equivalent of ocean basins.

crashing into Mars, and now filled with dust eroded from the Martian highlands and continually stirred by winds that whirl endlessly within the basins.

Equally as surprising, sinuous channels were discovered on Mars. They look as though they are dried up river beds equal in size to the Amazon River with clearly defined banks and intertwining sandbars, some with veined patterns of tributaries. The presence of such features came as a complete shock since scientists had concluded that water could not flow in large quantities as a liquid on Mars; the temperature is too low and the atmospheric pressure too low. And yet, if the erosion features have been made millions of years ago when conditions on Mars were very different from today, the big question is why the channels are so fresh looking. It would be expected that the violent annual dust storms would cover the channels with drifting sand and dust.

There may be extensive layers of permafrost all over Mars, as in the northern tundra of Earth. If such an area of permafrost were suddenly melted by volcanic activity, flash floods could be produced to wash out the channels. Such melting of permafrost might also account for the peculiar areas of slumped terrain which dot some regions of Mars.

The quantity of water still readily accessible at the surface of Mars is unknown. The quantities of carbon dioxide (in the atmosphere and the polar caps) suggest that there must also have been much water at one time on the planet, since water and carbon dioxide are both vented by active volcanoes. On Earth this water has remained and forms oceans, while the carbon dioxide was trapped into carbonates in the Earth's crust. It could very well be that Mars still retains its water as ice, both generally in the ocean basins and especially in the polar caps where they may be covered with alternating layers of dust and ice. The core of each polar cap might be ice several miles deep which has depressed the crust of Mars at the poles by its weight. The extensive seasonal caps are believed to be thin caps of frozen carbon dioxide—which disappear in summer. Mariner 9 showed that much smaller caps, probably of ice, do not disappear in summer on Mars.

There is still evidence of ancient ruined craters in the polar regions, but generally they show a laminated young terrain in which dust and ice may have accumulated over millions of years in distinct layers like stacked dishes. Edges of the stacks arc around each pole. These laminations seem to be too big to be yearly features. Rather they suggest long term climatic fluctuations on Mars which occur every 50,000 years or so.

Figure 7. Violent winds scream across the surface of Mars, creating dust storms and making wind-blown markings such as these streaks from Martian craters. These wind-deposited patterns cover large areas and cause changes to the surface that are observable from Earth and were once thought to be caused by growth of vegetation on Mars.

Explaining Changes on Mars

The classical variable features on Mars, at one time explained as a seasonal growth of vegetation, can now be explained on the basis of close-up observations by NASA's Mariner 9. They are of three general types—a uniform enhancement of contrast, irregular dark markings, and bright and dark areas that develop during the Martian seasons.

The uniform enhancement of contrast takes place when dust storms dissipate in an effect similar to a city skyline gradually becoming clearer as morning mists disperse with a rising sun. Splotches that appear on Mars are irregular dark markings that relate to the surface features of hills, valleys, and craters. They do not change greatly except to become indistinct when dust storms enshroud them. Finally, the bright and dark streaks that develop during Martian seasons appear to be the result of removal or deposit of wind-blown dust along characteristic wind patterns that repeat year after year. They are associated with the classical dark features of Mars which have been observed for centuries from Earth. Seen close-up in the space probe photographs they are made up of many smaller areas, often in the bottoms of craters and sometimes spilling over the crater walls into the surrounding territory and alongside ridges or scarps.

While it is generally accepted that the dark splotches on Mars may result from wind-blown dust, some close-ups of craters reveal a sand-dune type of surface forming the dark splotch. Thus they are most likely sand dunes. But there has been speculation that the splotches could re-

sult from Martian vegetation growing selectively in areas protected from the Martian winds and dust. This would apply especially to those dark markings close to ridges and remnants of crater walls.

Other dark areas are resolved into complex systems of streaks associated with craters, like tails of comets (Figure 7). Other streaks are, however, of bright material also emanating from craters. On Syrtis Major, the prominent, triangular-shaped marking mapped by Huygens, there are both dark and light streaks criss-crossing each other as though dark and light material has been deposited by complex winds. Variations in Syrtis Major are observed from Earth and may be the result of seasonal winds which first produce light streaks in one direction and then later dark streaks in another direction. Since Syrtis Major has been revealed as a region of very steep slope from highlands to an ocean basin, some winds may blow along the slope and others up and down it.

Bright streaks may originate from the fine dust of a major dust storm which collects in crater bottoms and is later blown from the crater by high winds. The dark streaks may be caused by other winds later removing the light material from an underlying dark terrain. The evidence today points toward the transport of light material by winds as the major cause of the changing appearance of Mars as seen from Earth.

Geology of Mars (Areology)

As pointed out earlier, the pictures returned from Mariner 9 reveal that Mars' surface has been molded not only by impacts but also by volcanic, tectonic, erosion, and sedimentary deposits (Figure 8). The moon-like areas are mainly in the southern hemisphere and mid and high latitudes. There are also some mare-type circular basins in the southern hemisphere which have been filled with smooth material. These seem to be old and considerably changed since their formation.

The evidence to date implies that Mars has differentiated, i.e. partly melted after its original formation, with the result that low density materials rose to form a crust and heavier materials sank to form a core. This is confirmed by the dust particles which are known to consist predominantly of silicon dioxide, showing that the low density materials must have risen to the surface of Mars. The thick covering of dust is most probably powdery with consistency of talcum.

Large parts of the northern hemisphere of Mars consist of smooth plains with very few craters upon them. They are like ancient ocean bottoms, lapping against higher land nearby. Also in the northern hemisphere there are four monstrous shield volcanoes that have steep-sided domes with cratered summits. Shield volcanoes are built up by repeated flows of lava that over millions of years pile up in sheets sloping away from the central crater. Widespread effects of vulcanism spread from the volcanoes as multiple lava flows, ridges, chains of craters and sinuous rilles.

The several volcanic regions on Mars appear to be connected with a general doming of the crust in the area, surrounded by extensive fracturing of the crust. The most extensive fracturing spreads over a large part of the planet from the Tharsis region where most of the big volcanoes are located. The great Valles Marineris, the Grand Canyon of Mars, seems to be a radial feature from the Tharsis dome.

Elsewhere on Mars there are examples of widespread crustal deformation; scarps, graben, faults, and mosaics of flat-topped blocks of crust. There are regions of chaotic terrain which consists of an intricate mixture of broken and jumbled blocks of crust. But there are no compressional scarps as seen on Mercury. Nor is there clear evidence of the motion of crustal plates as on Earth.

Mars thus emerges as a complex planet with a history very different from the Moon and Mercury, perhaps displaying an evolution between these planetary bodies and the Earth.

The Atmosphere of Mars

Scientists long disputed about the atmosphere of Mars. Before the space program a century of work based on observations from Earth had provided very little information about the atmosphere of Mars other than the presence of carbon dioxide, and traces of water vapor. The most commonly quoted value for the surface pressure of the Martian atmosphere was that determined by Dollfus, of 85 millibars, i.e. 8.5 percent of the pressure at sea level on Earth. This was equivalent to the pressure at 50,000 feet high in Earth's atmosphere; higher than most commercial jets fly.

However, when NASA spacecraft reached Mars new information about the planet's atmosphere became available and the results were not encouraging from the standpoint of life on the Red Planet. Surface pressure in the near equatorial regions of Mars ranges from a high of 0.89 percent of Earth's sea-level pressure in Hellas (a very low region), to a low of 0.28 percent in Tharsis (a high region of Mars). At high northern and southern latitudes pressures between 0.72 and 1.03 percent of Earth's sea-level pressure have been measured.

Figure 8. This most modern map of markings on Mars shows them in relationship to the geologic features revealed by the photographs taken by Mariner 9 in orbit around Mars for many months during 1971.

The pressure is very important since, taken in conjunction with the temperature, it determines whether or not water can exist as a liquid. At low pressures, water changes from ice to vapor when heated and does not pass through the liquid state believed essential to life. Clouds in the Martian atmosphere suggest the presence of water vapor and ice crystals as well as crystals of carbon dioxide. Cloud structure also shows downwind (lee) waves of craters generated by an east-to-west flow of the atmosphere. There are also thin haze layers above the lower atmosphere, seen in NASA pictures of the limb of the planet. These may be hazes of carbon dioxide and water ice crystals. Some limb hazes are also caused by dust clouds.

Clouds also make up the polar hoods which cover the polar cap areas in winter and are edged with weather systems similar to cyclones and cold fronts on Earth. As these storms dissipate closer to the equator their high winds produce regional dust storms.

On the high volcanic mountains clouds form each afternoon, and low mists surround the bases of the mountains at times. These are thought to be water clouds; possibly water vapor is still being exuded by the volcanoes. For years, Earth-based astronomers saw the neighborhoods of these volcanoes brighten in the afternoon. The brightenings are now known to be the result of the afternoon clouds which have been recorded in many photographs from Mariner 9.

Temperatures on Mars

The temperature of the Martian atmosphere at the surface is between —23°C (—10°F) and —3°C (26°F). But this temperature is dependent upon the amount of dust in the Martian atmosphere. The temperature of the surface itself behaves somewhat differently from that of the atmosphere. The maximum surface temperature occurs each day near the latitude of the point on the surface of Mars where the sun shines directly overhead, but at about one hour after local noon, irrespective of whether the atmosphere is dust filled or not.

Maximum atmospheric temperatures were measured by Mariner 9 late in the afternoon near latitude 60 degrees south during the dust storm of 1971, but as the dust cleared the atmospheric temperature maximum moved to coincide with the position of the surface temperature maximum.

Generally, conditions on Mars were found by Mariner 9 to be less harsh than previously thought —high enough atmospheric pressures in low lying regions for liquid water to be present at times; temperatures rising to 27°C (80°F) at local noon.

Pressures sufficient for water to exist as a liquid, i.e. above 6.1 millibars, occur during summer in large areas of Agyre, the western Margaritifer Sinus, Isidis Regio, and Hellas, and in a great belt circling the northern hemisphere between 40 and 50 degrees where there are several big valleys.

Mars as a Planet Today

In the telescope, Mars appears as a small fuzzy disc, reddish in general color, with greyish-green markings and topped by white polar caps. Mars is about half Earth's diameter with a gravity at its surface about one-third that of Earth. A 100 pound student on Earth would weigh only 38 pounds on Mars.

Temperatures on the surface generally reach 0°C (32°F) in early afternoon with some areas reaching 27°C (80°F). At night the temperature plunges to a frigid —123°C (—190°F).

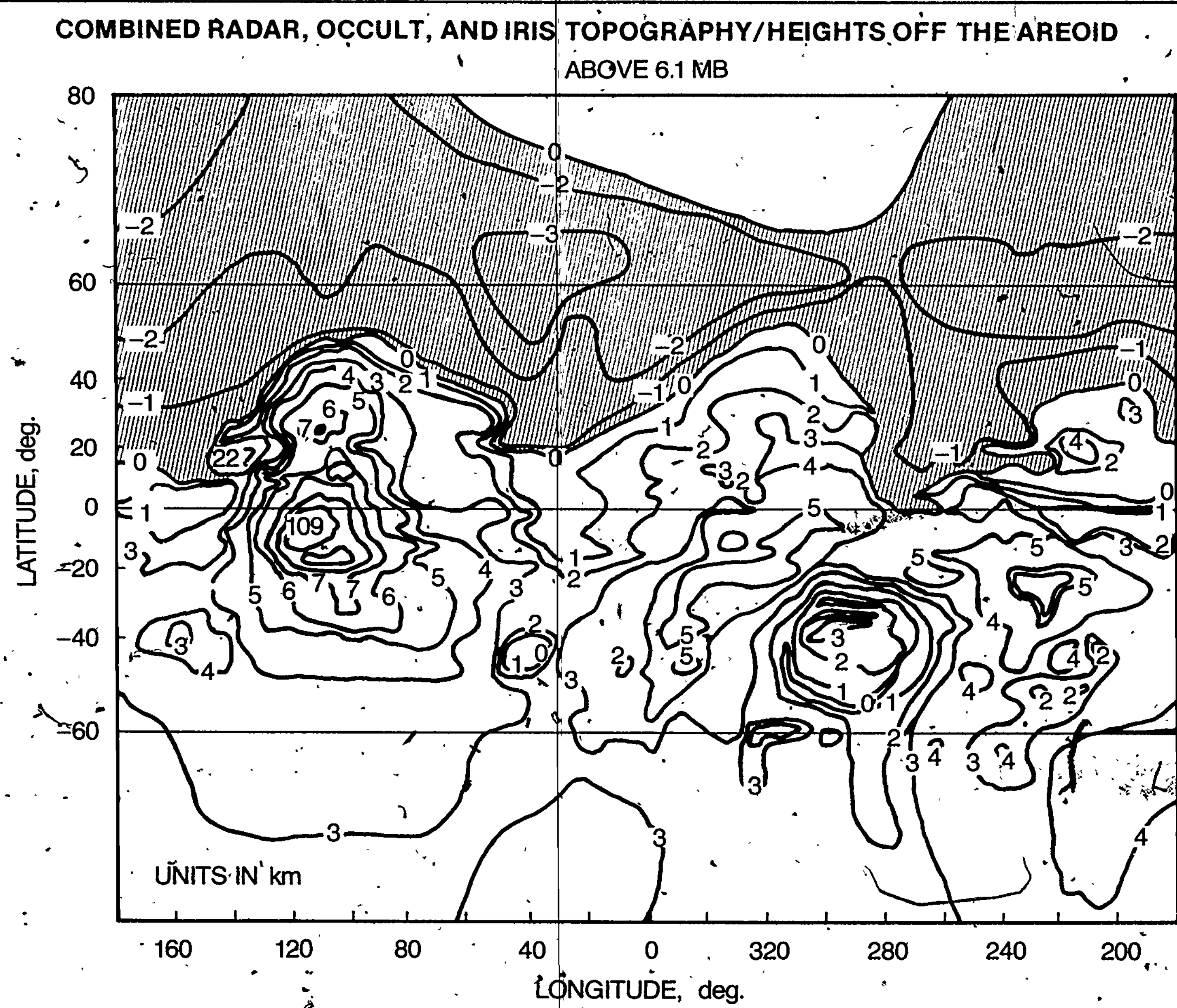

Figure 9. This contour map shows the height contours in kilometers above and below the level on Mars at which water can exist as a liquid.

It seems that Mars may be a planet that has partly made the transition from a moon-like body on which the surface was molded by impact of infalling bodies some 4 billion years ago, to a volcanically-active, water-dominated body such as the Earth. Extensive tectonic activity has changed large regions of Mars, pushing up domes of the crust and producing long linear faults. Additionally huge volcanoes have covered extensive areas with lava relatively recently in the Martian history.

The planet's surface has been eroded and sediments have been deposited over other vast areas. Channels transported enormous quantities of material from one part of Mars to another, just as rivers carry material from Earth's continents into the ocean basins. The only feasible explanation is that water has been generated in surges on Mars in sufficient quantities to wash the channels, only later to become locked in permanent ice or to be lost in space.

The possibility of life on Mars has again been raised because of the obvious water erosion and the pressures existing in low lying regions where liquid water could be present even today. And there could be evidence of fossil life from the time when water was more plentiful on Mars.

Thus the excitement of possibly finding life elsewhere in the Solar System is again stimulating scientific research to mount a new expedition to Mars that will land upon the planet's surface. This is Project Viking of the National Aeronautics and Space Administration, an unprecedented exploration of another world scheduled to start on the 200th anniversary of the founding of the United States.

STUDENT INVOLVEMENT

Project One

On the geologic map of Mars shown in Figure 8, superimpose the contours of Figure 9. This will show you where the lowest areas are on Mars. These are the areas where liquid water can today exist even in the rarefied atmosphere of Mars. Identify on your map, by shading or color, where you would land an expedition to search for life on the red planet. Make a table listing the name of the area, its latitude and longitude, its characteristics (cratered, plain, mountainous, valley). If you have only two opportunities to land a spacecraft on Mars which of these several areas would you pick, and why?

Project Two

Make a list of the unknowns about Mars that you would like to solve with a spacecraft that could land on Mars. What sort of experiments would you plan to solve your questions about Mars? Describe the equipment they would use, such as cameras, surface samplers, chemical analysis.

Project Three

Use the information in Figure 4 to make a plan map and a cross section of Olympus Mons on a scale of two inches to a hundred miles horizontally and one inch to 10 miles vertically. Refer to a good atlas and make a similar map and cross section of the main island of Hawaii on the same scale, including parts of this big shield volcano that are underneath the ocean surface. You will see the relative sizes of the biggest volcano on Earth and the biggest volcano on Mars. Scientists believe that the plate of Earth's crust carrying the Hawaiian Islands has moved steadily over a plume of hot magma coming from the Earth's mantle; so instead of building one big volcano as on Mars, this plume of lava has built up a series of islands across the Pacific Ocean. Try to estimate how big the volcano in the Pacific might have been if the material had not been spread out into the long chain of the Hawaiian Islands. Would it have been as big as Olympus Mons on Mars?

Suggested Reading

THE NEW MARS, W. K. Hartmann and O. Raper, NASA SP-337, 1974, U.S. Govt. Printing Office Stock Number 3300-00577

MARS FROM MARINER 9, B. C. Murray, *Scientific American*, v. 228, n. 1, January 1973, pp. 48-69

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